STABLE INTEGRATED MICROWAVE
TO
OPTICAL MODULATOR

TECHNICAL/FINANCIAL REPORT - CDRL ITEM A001-5)
(COVERING MARCH 2, 1991, TO JUNE 1, 1991)

PREPARED FOR:

OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
ATTENTION: YP, CODE: 1212
CONTRACT NUMBER: N00014-90-C-0073
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QUARTERLY REPORT FOR PERIOD 3/2/91 TO 6/1/91

1.0 Objective

The key technical objective for this research program is to integrate quantum well lasers (QWLs), detectors and GaAs MESFETs to produce a monolithic integrated microwave to optical modulator on semi-insulating GaAs substrates.

2.0 Programmatic Issues

A review of the first year's progress is scheduled for June 5 at Westinghouse in Baltimore.

3.0 Technical Progress

3.1 University of Illinois

3.1.1 Laser Diode Fabrication

Previously, two major problems were encountered during fabrication of low-threshold ridge-waveguide laser diodes. First a crucial silicon dioxide passivation layer was not adhering well to AlGaAs cladding material during a high-temperature (400°C) alloying step. This problem was completely alleviated by using pyrolytic decomposition of silane in oxygen (as opposed to E-beam evaporation) to deposit the silicon dioxide. The resulting oxide layer adheres well to the AlGaAs surfaces through all remaining fabrication steps. It was originally thought that this change would increase threshold current by increasing leakage current outside the laser ridge, however, the fabrication procedure was able to be modified so that the change has no ill effects. The second problem encountered was the inability to achieve ohmic contacts to the p-sides of the devices. This was solved using a shallow (1000Å) zinc diffusion into the grown wafers before device fabrication begins. The subsequent acceptor concentration at the surface is approximately 10E20cm^{-3} so that ohmic contact is easily achieved with a simple non-alloyed contacting scheme such as Cr/Au or Ti/Pt/Au.

Subsequently, low-threshold laser devices with excellent I-V characteristics were grown and fabricated on n-type substrates. These laser diodes exhibited turn-on voltages of approximately 1V with pulsed lasing threshold (room temperature) as low as 16 mA for 200μm long devices. The L-I characteristics were quite linear up to at least twice threshold, indicating good transverse mode stability and no facet breakdown, and devices were quite robust when driven

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to even higher current levels. In addition, at least one device was driven to lase CW at room temperature. This device (337μm long) was tested in a probe station with effectively no heat-sinking at room temperature, and yielded a CW threshold of 35 mA (pulsed threshold = 24 mA). The higher CW threshold indicates that some heating of the active layer is occurring, thus we have confidence that with good heat-sinking the CW threshold can be lowered to approach the pulsed value. Because these lasers will eventually be integrated with MESFETs on semi-insulating substrates, it is important that our devices lase CW at room temperature without the normal junction-side-down heat-sinking which is used for discrete laser diodes.

Recently, towards that end, planar laser structures have been grown and fabricated on semi-insulating GaAs substrates. These structures are currently being tested for their electrical and optical characteristics. In addition, we have incorporated an etch-stop layer for repeatable control of the height of the index-guiding/current-confining ridge used in these lasers. Devices on S.I. substrates should be available in mid-summer.

3.2 Westinghouse

3.2.1 Laser/MESFET Integration

A new fabrication approach for the integrated laser/detector/MESFET circuit has been proposed and is being studied. Potentially, this will be used in lieu of the original plan which involved growing MBE laser/detector structures on semi-insulating GaAs (rather than on n+ doped GaAs wafers as has been used for laser samples prepared previously), fabricating the lasers and detectors first, exposing the semi-insulating wafer via an etch, and fabricating MESFETs in these areas using selective ion implantation. The new process again involves active layer MBE growth on semi-insulating GaAs; however, in this case an n+/n- MESFET structure is first grown under the laser/detector structure. The profile is sketched in Figure 1. Again the diode/detector structures are fabricated first (at University of Illinois). However, the etch exposes not the SI GaAs but the underlying n+/n- layers which subsequently form the active FET layers. A standard double-ledge, recessed MESFET fabrication scenario is used on this area with passive components and interconnects fabricated using standard processes. The process flow is given in Table 1 and illustrated in Figure 2. It is believed that the combination of DSW and direct-write e-beam exposure technologies will meet the resolution requirements despite the several microns of surface topology on the wafer after laser/detector fabrication. A major advantage of

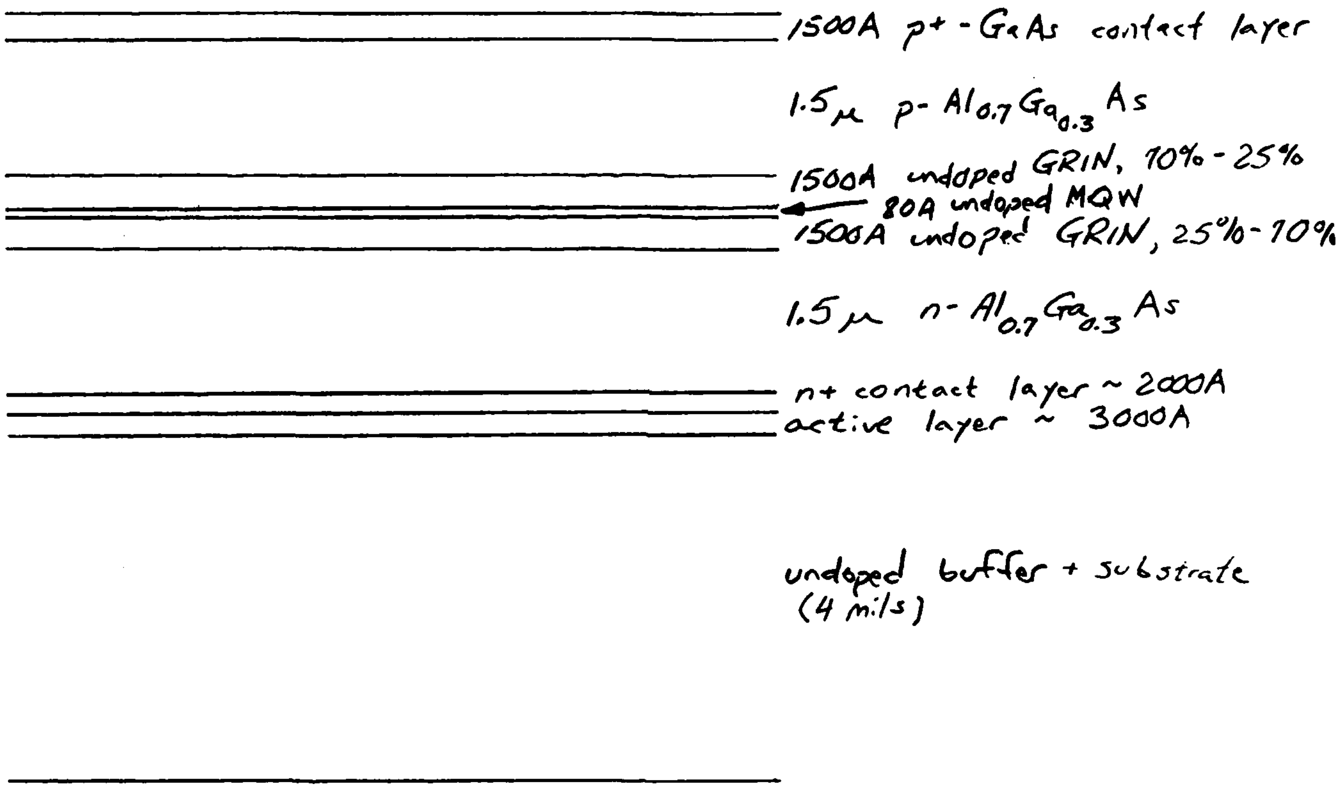

Figure 1. Proposed MBE Layers for Both MESFET and Laser Fabrication.

Table 1. Proposed Process Flow Steps

UNIV. OF IL	1.	MBE PROFILE GROWTH	
	2.	ZN-DIFFUSION IN AMPOULE	
	3.	ETCH RIDGE-WAVEGUIDE MQW STRUCTURE AND P-I-N MQW PHOTODETECTOR STRUCTURES	
	4.	LEAVE EXPOSED N+ BETWEEN STRUCTURES	
	5.	DEPOSIT/PATTERN SiO_2	
(W)	6.	ETCH MESAS (MESFETs AND LASERS/DETECTORS)	DSW LITHOGRAPHY
	7.	PATTERN P-OHMICS (TIPTAU OR CRAU)	
	8.	PATTERN N-OHMICS (AUGENIAU)	
	9.	ALLOY ($430^{\circ}C$, 30C, RTA)	
	10.	CHANNEL PATTERN/ETCH	
	11.	GATE PATTERN/RECESS/DEPOSITION/LIFT OFF (TIPTAU)	DIRECT-WRITE E-BEAM
	12.	OVERLAY METALLIZATION	DSW LITHOGRAPHY
	13.	AIR BRIDGE FABRICATION	
	14.	WAFER THINNING	
	15.	VIA RIE	
	16.	BACK-METALLIZE	

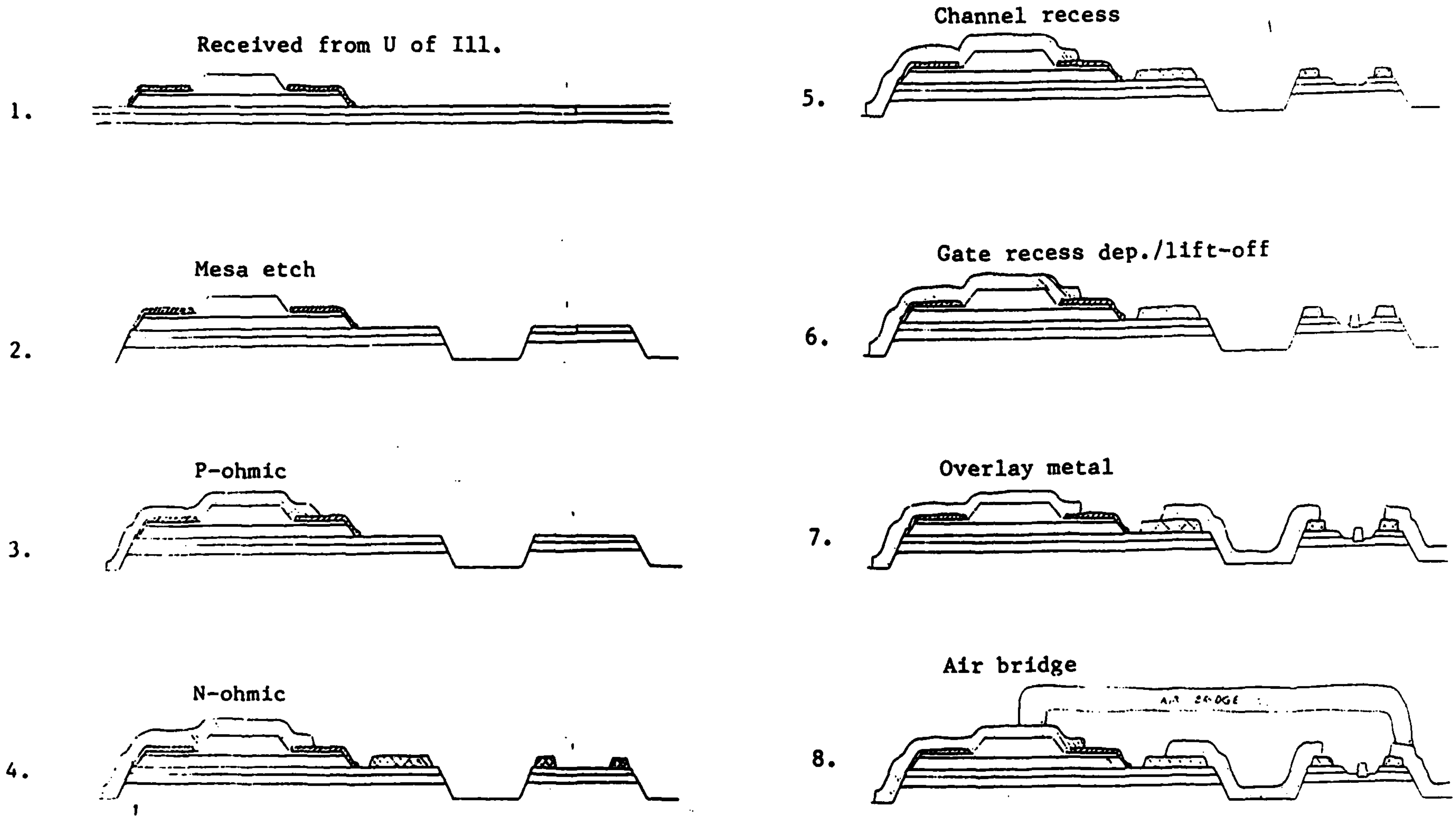

Figure 2. Proposed Process Flow.

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this process is that it eliminates the implant and high-temperature anneal process steps required for the original process sequence.

Initial issues to be resolved, action items, and responsibility are summarized in Table 2.

Table 2. Identified Process Compatibility Issues and Action Items

Issue	Action Items	Responsibility
Characterize MESFETs for design in control circuit	i) Determine MESFET requirements, design profile, and supply 3" wafers. ii) Grow MBE active layer like that anticipated for the final IC iii) Fabricate/characterize MESFETs	(W) Univ. of IL (W)
Is MESFET fabrication compatible with the anticipated surface topology?	Layout a "dummy" circuit with 3-4μ high islands the size of lasers/detectors and fabricate "FET-like" structures on it	(W)
Finalize laser/detector fabrication sequence, including ohmic contacts, passivation, and facet etching, and assign responsibility between Univ. of IL and (W)	On-going component fabrication and testing	Univ. of IL
Determine a process for stopping etch of laser/detector structures at the n+ surface for MESFETs	Evaluate timed etch and AlGaAs/GaAs selective etch stop approaches i) Material growth ii) Process demonstration/evaluation	 Univ. of IL Joint

3.2.2 Stabilization Loop Experiments

Improved Coupling Optics

As indicated in previous reports, the evaluation of laser diode noise and modulation behavior at microwave frequencies requires efficient optical power delivery to a wideband photodetector with a minimum of energy reflected back into the laser diode. To this end the enhanced coupling optics shown in Figure 3 have been built and tested. Both lens groups provide diffraction limited performance and are A.R. coated at 830 nm wavelength. The rear element of the focusing group is compensated to minimize spherical abberation introduced by the sapphire window protecting the 6 GHz bandwidth photodiode. Optical energy reflected from the window and diode is deflected by tilting the photodetector assembly with respect to the optical axis. A glass plate beamsplitter in the collimated space permits beamsampling for radiometer measurements. Using an earlier type of SQW laser diode operating at 50 mA the collimating lens group collected 2 mW of optical power in 0.5 N.A., and the focusing group delivered 1.5 mW of this to the 50 micrometer diameter photodiode.

Stabilization Loop

Work has continued in the development of a stabilization loop to set laser diode operating current and compensate for temperature dependence of light output plus device aging. Figure 4 shows an early version using discrete components built to demonstrate that a simple loop is feasible using a high transconductance FET (170 mS) in a source follower configuration. A closed loop gain of approximately 100 was demonstrated by shunting 10 mA of the normal 50 mA laser operating current through a bypass resistor, the measured change in current through the laser diode being only 0.1 mA. It was noted however that the loop gain is strongly dependent upon the coupling between laser and photodetector, the latter operating in the photoconductive mode under reverse bias. A drain to source voltage drop as low as 1 V did not adversely affect circuit performance and is beneficial in minimizing power dissipation. The stabilization loop is currently in the process of modification to conform with the configuration shown in Figure 5. This hybrid circuit uses a high transconductance (typ. 200 mS) Westinghouse MESFET in conjunction with as available Hitachi laser diode whose operating current regime is comparable with our SQW laser diodes. The Hitachi laser has been provisionally substituted because of the limited availability of both older SQW and newer MQW laser diodes. Although suitable for stabilization loop development, the HLP-1400 modulation bandwidth is less than 3 GHz and its

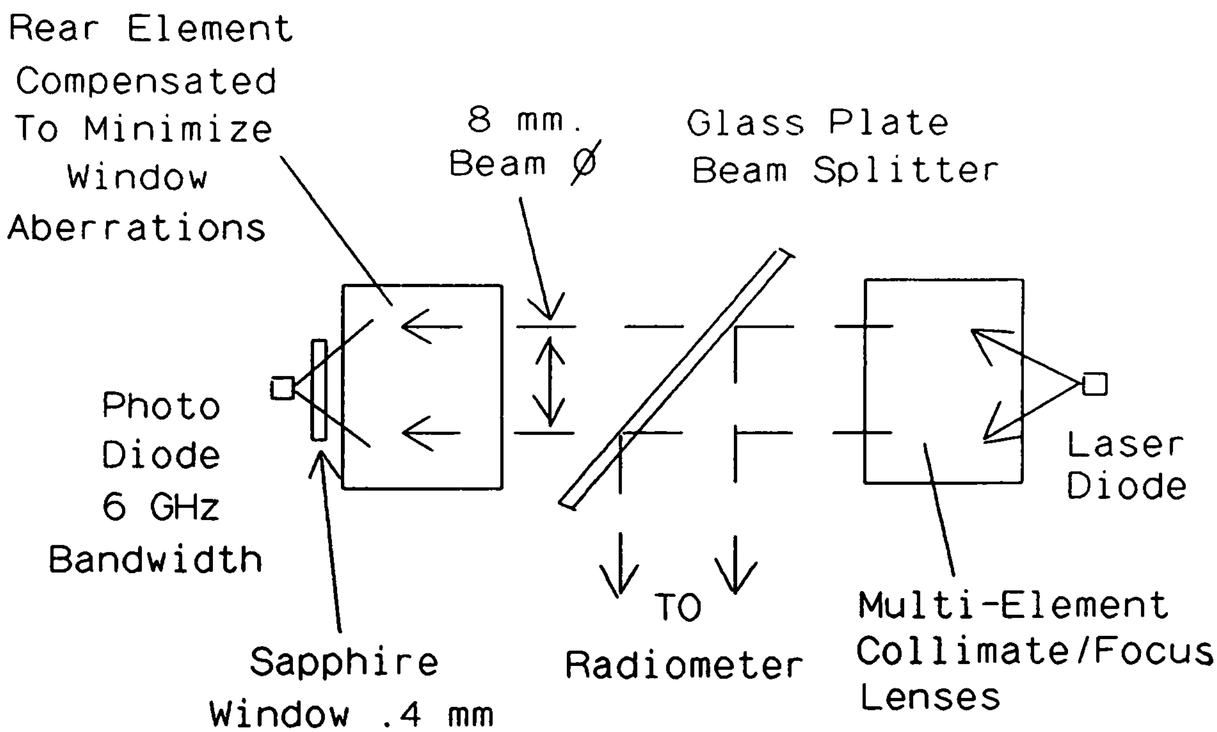

Figure 3. Enhanced Coupling Optics.

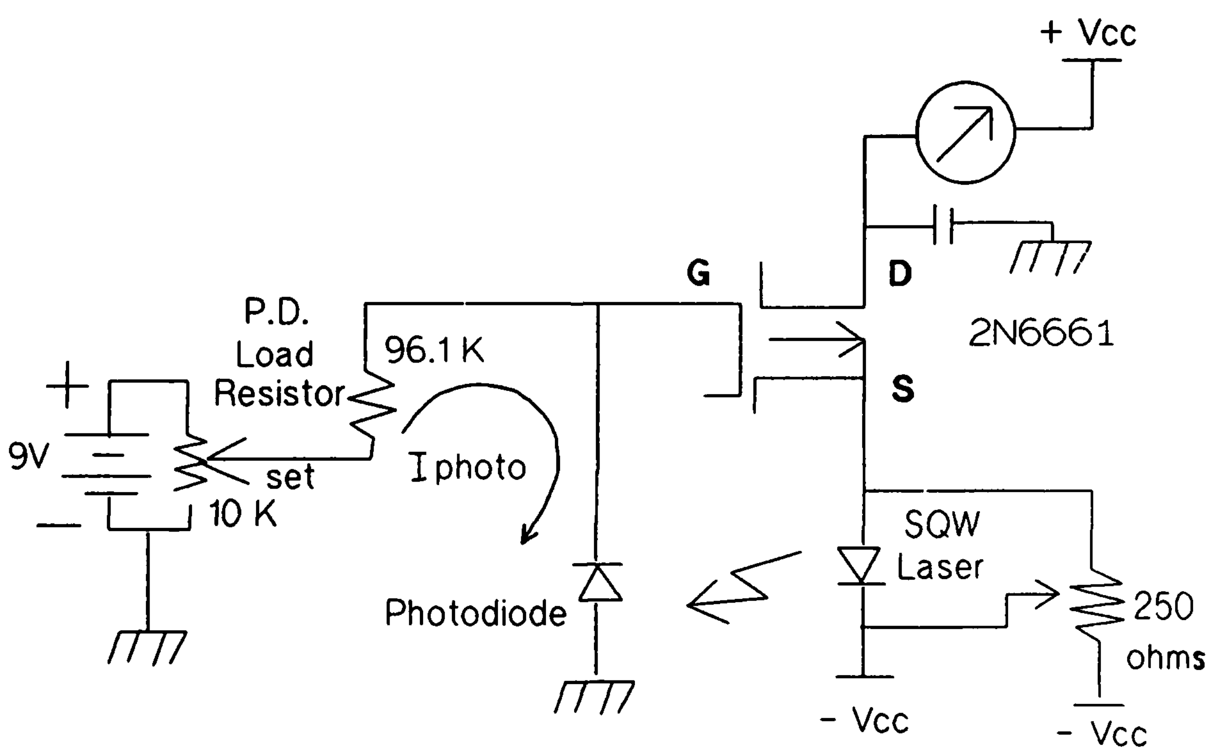

Figure 4. Stabilization Loop Using Enhancement Mode MOSFET.

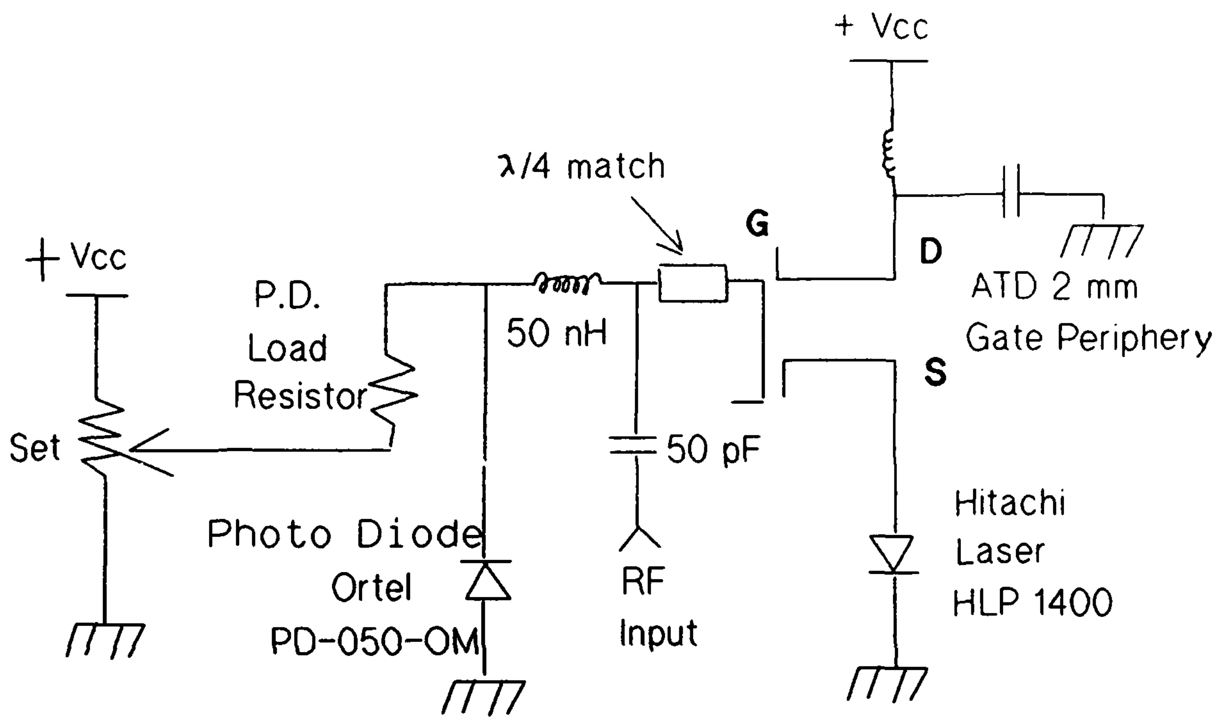

Figure 5. Stabilization Loop Using Depletion Mode MESFET.

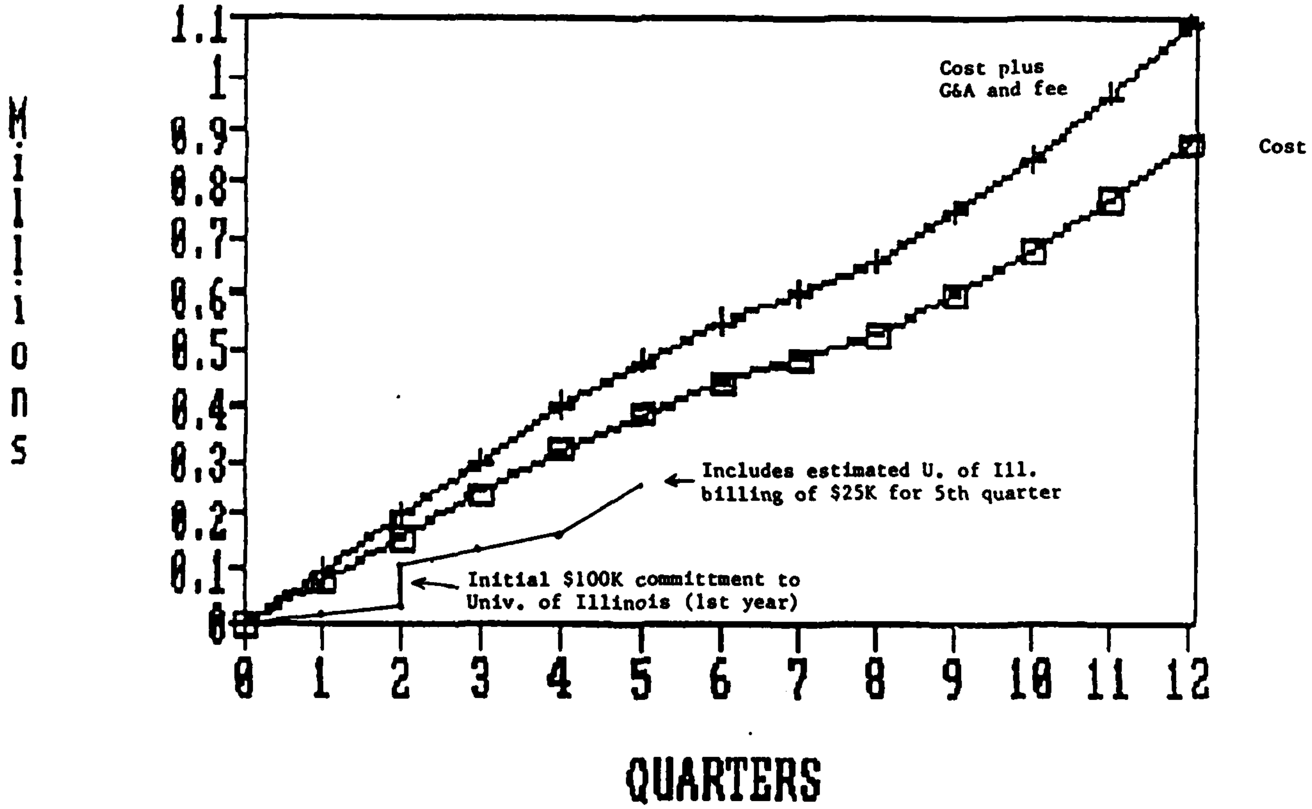

Figure 6. Program Spending.

use at microwave frequencies is limited by packaging constraints. We therefore plan to add the bias network and matching section only when selected MQW laser diodes are available.

University of Illinois MQW Laser Diode

Late in the current reporting period samples of the latest ridge structure MQW laser diodes were received from the University of Illinois. These are being mounted P contact down on Indium deposited copper heatsink structures which are equipped with individual microwave transmission line substrates and RF connectors for each diode. Problems have been experienced in achieving good adhesion between the pure Indium deposit and the gold P contact area even with the use of a specially formulated flux. Good thermal contact is essential when using these sample diodes in CW operation as they exhibit higher than normal series resistance. We are currently investigating the integrity of the Indium deposition process and plan to mount the remaining samples in the reducing environment of a hydrogen furnace.

4.0 Financial

Program spending to date, both planned and actual, is shown in Figure 6. The figures shown are direct cost and do not include G&A or Fee. While spending is still below planned as a result of the delayed start at the University of Illinois (due to the Spring 1990 flood), the spending rate, as evidenced by the slope of the curve, is increasing. Actual spending is expected to gradually approach the "planned" curve as the integration effort intensifies in the next six months.

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